INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN PROGRESSIVE EDUCATION & DEVELOPMENT

OPEN ACCESS JOURNAL

Vol 14, Issue 4, (2025) E-ISSN: 2226-6348

Working Memory Capacity and Dual-Task Interference in Following Instructions

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DOI Link: http://dx.doi.org/10.6007/IJARPED/v14-i4/26716

Published Online: 28 October 2025

Abstract

This study employed a dual-task approach to examine the effects of working memory capacity (WMC) on following spoken and written instructions. The participants comprised 26 individuals with high WMC and 26 with low WMC. They completed two types of instruction tasks under interference conditions: spoken instructions paired with an articulatory suppression task, and written instructions paired with a tapping task. In the spoken condition, recall was verbal, whereas in the written condition, recall was action. The results revealed significant main effects of both WMC and dual-task interference on instruction-following performance, as measured by total correct recall. Moreover, a significant interaction between WMC and dual-task interference was found, indicating that interference impaired working memory performance and reduced recall accuracy. Performance was most affected in the verbal recall of spoken instructions with articulatory suppression, especially in the low WMC group.

Keywords: Working Memory Capacity, Dual-Task Interference, Following Instructions

Introduction

Working memory is a limited-capacity system responsible for storing, manipulating, and processing information over short periods (Baddeley & Hitch, 1974; Gathercole et al., 2008). Because of this limitation, processing speed and ability vary across individuals (Engle et al., 1992). Past studies have shown that performance differs between high- and low-WMC groups in terms of information processing and recall, as well as in their ability to control distractors and suppress interference from irrelevant information (Engle, 2002).

Working memory storage is disrupted when distractors compete for the same domain of information processing (Pashler, 1994). For example, when a person is trying to complete a reading task while simultaneously being distracted by verbal noise from friends asking irrelevant questions, performance on the reading task declines. This occurs because both reading and processing the questions compete for the phonological loop, thereby reducing focus. The effect of interference is significant because both tasks draw on the same limited cognitive resources within working memory (Nijboer et al., 2016). Moreover, the degree and strength of interference contribute to performance differences, which manifest as variations in working memory capacity (Klingberg, 1998). This phenomenon, known as the task interference effect, occurs because two tasks require overlapping brain areas to process stimuli (He et al., 2022). In contrast, tasks with low variability and consistent repetition have relatively little impact on working memory performance during retrieval (Oberauer et al., 2004). Allen and Waterman (2015) noted that differences between high- and low-WMC individuals were most evident in tasks involving verbal recall rather than action recall.

Past studies (Yang et al., 2014; Yang et al., 2016; Yang et al., 2024) have reported that individuals perform better on spoken and written instruction tasks during action recall compared to verbal recall. Similarly, performance is generally better when no interference is present than when interference occurs (Yang et al., 2016). Yang et al. (2016) reported that working memory performance is affected by the presence of dual tasks such as articulatory suppression, backward counting, or tapping, which in turn reduces instruction-following performance. Participants performed better on action recall tasks compared to verbal recall tasks, as action recall was less affected by dual-task interference (Yang et al., 2016). Dual-task interference primarily disrupted instruction-following due to competition for resources within the phonological loop. Task complexity, especially in novel or attentionally demanding tasks, can impair performance (Draheim et al., 2022).

In comparison to past studies on the role of working memory in following instructions using dual-task designs, fewer studies have emphasized the effects of working memory capacity (WMC) and dual-task interference on instruction-following performance. Moreover, there is a notable lack of research addressing this topic within the Malaysian context. The present study contributes to filling this gap by investigating instruction-following performance under dual-task conditions using tasks conducted entirely in *Bahasa Melayu*. Existing theories suggest that individuals with high WMC generally perform better than those with low WMC across most tasks. However, further investigation is needed to examine this relationship within the context of the present study. Most previous studies have focused on comparing different treatments or task conditions within dual-task paradigms, with less emphasis on the role of capacity differences. Therefore, these theoretical and methodological gaps provide an opportunity to investigate how working memory capacity and types of instructions, in the presence of dual-task interference, influence instruction-following performance as measured by the total correct recall of instructions.

Accordingly, the following research hypotheses were formulated to guide the study’s main objective:

H1-There is no main effect of WMC (high vs low WMC) on following instructions performance based on the total correct recall of the instructions.

H2- There is no main effect of types of instructions with dual task interference (spoken instructions with articulatory suppression task, and written instructions with tapping task) on following instructions performance based on the total correct recall of the instructions.

H3- There is no significant interaction between working memory capacity (high vs low) and types of instructions with dual task interference (spoken instructions with articulatory suppression task, and written instructions with tapping task) on following instructions performance based on the total correct recall of the instructions.

Through this study, we can better understand the theoretical significance of the role and effects of working memory capacity. Specifically, this study is grounded based on the principle of attentional control theory (Engle, 2002). The findings highlight that the impact of different types of instructions under interference is not always negative, particularly when instructions are recalled through action recall. In terms of practical significance, this study guides the design of instructional delivery by simplifying content, incorporating scaffolding techniques, and minimising distractors to improve learning effectiveness. Stakeholders in various settings that rely on instruction-following activities need to recognise how interference can reduce compliance and accuracy.

Literature Review

Past studies have reported that working memory is affected by the presence of dual-task interference during instruction-following tasks (Engle et al., 1992; Yang et al., 2014; Yang et al., 2015; Yang et al., 2016). Jaroslawska et al. (2016) investigated the effect of WMC on following spoken instruction performance among 42 children aged 7–11 across three conditions: a real-world task using physical 3D objects, a virtual classroom task, and a multi-location virtual school navigation task. Their findings revealed that WMC had a significant effect in all three tasks, particularly in the multi-location navigation task. In this context, verbal WMC played a crucial role in retaining information and executing instructions, requiring a high level of attentional control. These results suggest that working memory capacity can be challenged by task complexity and the presence of dual-task distractors, which may weaken attentional control and increase cognitive load among children.

In a follow-up study, Jaroslawska et al. (2018) conducted three dual-task experiments to examine whether the motor storage system could enhance action recall performance compared to verbal recall. They applied different dual-task interferences: articulatory suppression, backward counting, and repetitive fine or gross motor gestures to disrupt performance on encoded spoken instructions recalled verbally or through action. Results showed that articulatory suppression and backward counting did not affect action recall performance, except when motor suppression was present. However, these two interferences significantly impaired verbal recall performance, as they competed for the same storage system, namely the phonological loop. Buszard et al. (2017) reported that individual differences in WMC also affected performance on motor learning instruction tasks. Their findings showed that dual-task interference (auditory probes) imposed additional cognitive load on children with low WMC (aged 8–10) while performing a basketball shooting task with multiple instructions, compared to children with high WMC.

Yang et al. (2015) conducted a series of experimental tasks with young adults, who were tested using spoken instruction tasks containing three elements (movement, object, and colour; e.g., “pick up the red pencil, then put it into the black box”). Participants were required to perform either verbal or action recall. Interference tasks were introduced to examine their impact on different components of working memory: articulatory suppression (targeting the phonological loop), backward counting (impairing the central executive), and eye closure (interfering with the visuospatial sketchpad). Results indicated that all interferences impaired verbal recall performance. However, action recall performance remained relatively unaffected, likely due to the additional support provided by the motoric system, which enhanced recall performance. Similarly, Makri and Fiske (2023) found that children’s verbal recall performance was negatively affected by dual-task interferences (articulatory suppression, backward counting, and motor suppression), which targeted different subcomponents of working memory. However, action recall performance was not significantly impacted, supporting the well-established advantage of action recall reported in previous studies (e.g., Yang et al., 2016; Jaroslawska et al., 2016). Together, these findings suggest that action recall offers a performance advantage even under conditions of interference.

Overall, these studies demonstrate that dual-task interference significantly affects instruction-following performance, particularly when the interference task shares similar characteristics with the primary task. This effect is more pronounced for verbal recall than action recall. When interference is challenging, the encoding process is disrupted (Conway & Engle, 1994). Research has also shown that individuals with high WMC perform better under intrusive cognitive interference, reporting fewer unwanted thoughts and intrusive memories compared to those with low WMC. This highlights that working memory capacity is most effective when individuals can control attention and suppress distractors (Rosen & Engle, 1998).

Supporting this view, Kane and Engle (2003) found that individuals with low WMC exhibited weaker attentional control when tested with incongruent trials (e.g., the word “red” printed in blue) on the Stroop task. This experiment confirmed that the presence of interference impairs attentional control and reduces recall performance. Similarly, Baddeley et al. (2001) reported that arithmetic task performance was impaired under articulatory suppression during task-switching conditions, which require both high attentional control and the ability to ignore distractions. Redick et al. (2011) also found that individuals with low WMC performed worse on a go/no-go task requiring high inhibitory control, particularly under conditions with frequent stimuli and shorter temporal lags. These findings collectively suggest that low WMC individuals experience greater difficulty in interference-rich environments and struggle to maintain attentional focus when updating and retrieving information.

In summary, evidence across these studies indicates that dual-task interference disrupts the attentional control processes that support working memory, thereby impairing instruction-following performance. Individuals with low WMC are particularly inclined to such interference, as they possess limited capacity to maintain goal-relevant representations amid competing demands. Grounded in Engle’s controlled attention theory (2002), these findings underscore that WMC reflects an individual’s ability to allocate attention effectively, suppress distractions, and sustain goal-directed processing under cognitively demanding conditions.

Method

Design

This study employed 2x2 mixed factorial design, WMC was a between-subjects design (high vs low WMC), and types of instructions with dual task interference (spoken instructions with articulatory suppression task; and written instructions with tapping task) were within-subject design.

Participants

A total of 52 participants (26 with high WMC and 26 with low WMC), aged between 18 and 26 years, took part in this study. Most were undergraduate university students. Participants were recruited through convenience sampling and were required to meet the following criteria: proficiency in *Bahasa Melayu* (writing, speaking, and reading), age between 18 and 26 years, and no history of hearing impairment, visual disorders (e.g., blindsight), neurological conditions, or psychiatric disorders. As compensation for their time and commitment, each participant received an honorarium of RM40.

Materials

There are three main tasks used in this study. All experimental tasks in this study were developed and administered in *Bahasa Melayu*. The details are as follows:

1-Working memory capacity tasks (Reading Span Task & Rotation Span Task)

Two working memory tasks were employed to assess verbal and visuospatial working memory. An adapted version of the reading span task, based on the frameworks of Engle et al. (1999) and Kane et al. (2004), was used to measure individual verbal working memory capacity. In the reading span task, participants were required to read sentences presented on the screen aloud and then immediately indicate whether each sentence was "logik or "tidak logik". At the same time, they had to remember a word displayed below each sentence until the recall phase. During the recall phase, participants had to write the words that they remembered. The task consisted of four blocks, each comprising three trials. Two practice trials were provided before the real trials.

The second task, the rotation span task, was used to assess visuospatial working memory capacity. This task consisted of four blocks with three trials per block. Two practice trials were provided before the real trials. Participants were required to respond "tepat" or "condong" when presented with blue arrows. When red arrows appeared, they were instructed to remember the arrow's direction without verbalising it. During the recall phase, participants had to state the sequence of the red arrow directions (000°/360°, 45°, 90°, 135°, 180°, 225°, 270°, 315°) for each trial using the response sheet provided. This task was adapted from Shah and Miyake (1996) and later refined by Kane et al. (2004). The combined scores from both tasks were then used to categorise participants into high and low WMC groups through a median split analysis.

2-Following instructions task (spoken instructions) with articulatory suppression task

This task consisted of four blocks, with each block comprising three trials. Each trial contained three main elements: movement, object, and colour, presented in the form of instructions. The length of the instructions varied across blocks. For example, in Block 1 each trial included two instruction sentences, whereas in Block 2 each trial contained three sentences. For instance, a sample instruction in Trial 1 of Block 1 was: *sentuh pen merah, pusing sudu biru* (touch red pen, rotate blue spoon). Two practice trials were provided before the real trials.

During the task, participants listened to pre-recorded instructions played through computer speakers while simultaneously performing an articulatory suppression task by verbally repeating "7-5-3" as a distractor to the spoken instructions. When prompted by the cue "*SILA ULANG*" (please repeat), participants were required to recall the instructions verbally. This task was adapted from the framework of Yang et al. (2016).

3-Following instructions task (written instructions) with tapping task

This task consisted of four blocks, with each block comprising three trials. Each trial contained three main elements: movement, object, and colour, presented in the form of instructions. The length of the instructions varied across blocks. For example, in Block 1 each trial included two instruction sentences, whereas in Block 2 each trial contained three sentences. For instance, a sample instruction in Trial 1 of Block 1 was: *angkat pensil hitam, tolak pinggan jingga* (lift black pencil, push orange plate). Two practice trials were provided before the real trials.

During the task, participants were required to read the written instructions presented at the centre of the computer screen aloud, while simultaneously performing tapping task by gently tapping each square cube in a counter-clockwise sequence (refer to Figure 1). When they encountered a slide displaying the cue "*SILA ULANG*" (please repeat), participants had to perform action recall for that trial. This task was adapted from the framework of Yang et al. (2016).

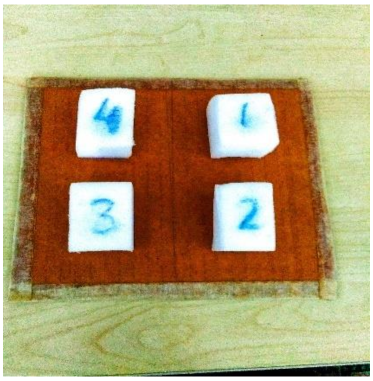

Figure 1 Tapping Task Board

The following are the details of the elements in the following instructions tasks in both spoken and written instructions tasks (refer to Figure 2):

1-Movements: *tolak,tarik, sentuh, ketuk, pusing, dan angkat* (push, pull, touch, knock, rotate, and lift)

2-Objects: *pen, pensil, pinggan, sudu, penyepit, dan kain* (pen, pencil, plate, spoon, clip, and cloth)

3-Colours: *jingga, kuning, hijau, hitam, merah, dan biru* (orange, yellow, green, black, red, and blue)

Figure 2 Objects and Their Colours for the Following Instructions Tasks

All the objects were presented on the table throughout the experiment, and the location of each object was in the same position throughout the experiment.

Procedure

Before the experiment began, the researcher provided participants with an informed consent form. They were asked to read its contents carefully and sign it if they agreed to participate. The researcher then gave a general explanation of the experimental procedures. The first task was the reading span task, designed to assess verbal working memory capacity. In this task, participants read sentences presented on the screen, each followed by a word to be remembered, though they were not allowed to say the word aloud. After reading each sentence, they immediately indicated whether it was "*logik*" or "*tidak logik"*. The number of sentences varied across trials. For example, in the sentence "*bola boleh disepak*" (the ball can be kicked), which is logical, the word "*cuti*" (holiday) would appear underneath and had to be remembered until the recall phase.

The second task was the rotation span task, which assessed visuospatial working memory. Participants were required to respond "*tepat*" or "*condong*" when blue arrows appeared. However, when red arrows appeared, they remained silent and had to retain the arrow's direction until recall. At recall time, participants referred to a direction table to reproduce the sequence of red arrows. The recorded scores from both tasks were combined and used to classify participants' working memory capacity (WMC). The partial-credit unit scoring method outlined by Conway et al. (2005) was used to score and calculate each correct answer in reading and rotation span tasks.

The next phase of the experiment involved the instruction-following tasks under dual-task conditions, with both spoken and written instructions. First, the researcher introduced the task elements (six movements, six objects, and six colours) and provided two practice trials for the spoken instruction condition, accompanied by the articulatory suppression task. In this condition, participants listened to instructions presented via computer speakers while simultaneously repeating "7-5-3" at a moderate pace. When they heard the cue "*SILA ULANG*" (please repeat), they were required to verbally recall the correct sequence of instructions for that trial. If unable to recall, they could respond with "*TIDAK INGAT*" (do not remember) or attempt an answer, even if incorrect. Each correctly recalled instruction in the correct sequence was awarded one point.

After a three-minute rest, participants completed the written instruction condition under dual-task interference, which involved a tapping task. They first completed two practice trials before beginning the experimental trials. The written condition consisted of four blocks, each with three trials of varying sentence lengths. The instructions were similar to those in the spoken condition but were counterbalanced across blocks so that the order did not match the spoken trials. In this task, participants read the instructions displayed on the computer screen aloud while simultaneously tapping the cubes on a tapping board in a clockwise sequence (4-3-2-1). When the slide displaying "*SILA ULANG*" appeared, they recalled and reproduced the instructed sequence in the form of actions only. Each correct action in the correct order was awarded one point.

All data were analysed using a two-way mixed factorial ANOVA in SPSS version 29.0. This study received ethical approval from the University Ethics Committee: HREC(NM)/2023 (2)/56.

Results

Descriptive findings

Data for the total WMC score (derived from the reading span and rotation span tasks) were obtained by summing the scores from both tasks. Participants with scores at or above 12.405 were classified as high WMC, while those with scores below 12.405 were classified as low WMC. As a result, 26 participants were grouped as high WMC and 26 as low WMC. As shown in Table 1, the high WMC group performed better (M = 16.42, SD = 6.33) than the low WMC group (M = 10.61, SD = 3.94) when following spoken instructions under articulatory suppression interference. However, performance in the written instruction condition with the tapping task as interference did not differ significantly between groups (high WMC: M = 18.08, SD = 3.84; low WMC: M = 17.35, SD = 3.00). Overall, performance on the spoken instruction task with verbal recall was more strongly affected by articulatory suppression as dual-task interference compared to the action recall performance in the written instruction task with tapping interference. Both groups performed better in the written instruction condition, with particularly notable improvement in the low WMC group compared to their own performance on the spoken instruction task with articulatory suppression.

Table 1

Mean and standard deviation of the high and low WMC performance for each type of instruction and recall

Instructions Type (Recall Type)	**High WMC (N=26)**	**Low WMC (N=26)**
Spoken Instructions + Articulatory Suppression Task (Verbal Recall)	16.42 (6.33)	10.61 (3.94)
Spoken Instructions + Tapping Task (Action Recall)	18.08 (3.84)	17.35(3.00)

Inferential Findings

The two-way mixed factorial ANOVA revealed a significant main effect of WMC (Hypothesis 1), F (1, 50) = 10.027, p = .003, partial η^2 = .167. This finding indicates that, regardless of the type of instruction and the presence of dual-task interference, there was a significant performance difference between the high and low WMC groups based on the total correct recall of instructions. Therefore, the null hypothesis for Hypothesis 1 was rejected.

For Hypothesis 2, the analysis showed a significant main effect of instruction type with dual-task interference (spoken instructions + articulatory suppression versus written instructions + tapping task), $F(1, 50) = 38.304$, $p < .001$, partial $\eta^2 = .434$. This suggests that, irrespective of WMC group, performance differed across instruction types due to the presence of dual-task interference, which acted as a distractor and influenced recall performance. Thus, the null hypothesis for Hypothesis 2 was also rejected.

Finally, the analysis of Hypothesis 3 revealed a significant interaction effect between WMC and instruction type under dual-task interference, $F(1, 50) = 14.043$, $p < .001$, partial $\eta^2 = .219$. This indicates that the performance differences in spoken versus written instruction tasks with dual-task interference were moderated by WMC, with high WMC participants generally outperforming low WMC participants in the spoken instruction condition with articulatory suppression as a distractor. Accordingly, the null hypothesis for Hypothesis 3 was rejected.

Discussion

Referring to the general findings of this study, the high WMC group consistently outperformed the low WMC group. This difference may be attributed to their greater ability to suppress distractors and sustain attention when retaining instructions. The performance gap was most evident during the spoken instructions task with articulatory suppression as a distractor. This result aligns with the controlled attention theory (Engle, 2002), which emphasises the ability of high-WMC individuals to inhibit distractors. Interestingly, in the written instructions task with the tapping task as a distractor, no significant differences were observed between the two groups. In this case, the low WMC group appeared to benefit from action recall, which was less affected by the tapping task. This finding is consistent with previous studies (Jaroslawska et al., 2016; Yang et al., 2016; Jaroslawska et al., 2018).

The findings for Hypothesis 1 indicate that WMC had a significant effect on instruction-following performance, with a large effect size (partial $\eta^2 = .167$). A reasonable explanation for this effect lies in individual differences in attentional control, particularly among high-WMC individuals. They were able to retain information for longer periods and suppress distractors, especially during spoken instruction tasks with articulatory suppression. This outcome supports attentional control theory (Engle, 2002) and the task interference effect (He et al., 2022). The observed performance differences between high and low WMC groups in following spoken instructions with articulatory suppression likely reflect the added cognitive load imposed by articulatory suppression, which taxed the limited WMC capacity of both groups, particularly the low WMC group.

The results of Hypothesis 2 revealed a significant effect of instruction type with dual-task interference in following instructions, with a large effect size (partial $\eta^2 = .434$). This finding demonstrates that dual-task significantly influences instructional delivery and instruction-following performance. Specifically, articulatory suppression strongly impaired verbal recall by competing for limited working memory resources. Participants had to listen to recorded spoken instructions while simultaneously performing verbal repetition of “7-5-3” until they heard the prompt “SILA ULANG” in each trial. This dual demand likely reduced recall accuracy. Despite the interference of the tapping task during the written instructions task, participants showed relatively better performance in action recall compared to verbal recall (Jaroslawska et al., 2018).

The findings for Hypothesis 3 revealed a significant interaction between WMC and instruction type under dual-task interference, with a large effect size (partial $\eta^2 = .219$). This interaction suggests that both high and low WMC groups encountered greater difficulty following spoken instructions with articulatory suppression, as this condition required verbal recall, compared to written instructions with the tapping task. The performance differences between groups indicate that WMC interacts with instruction type and interference, particularly under conditions of verbal recall (Makri & Fiske, 2023). The low-span group performed poorly during verbal recall of spoken instructions with interference (Redick et al., 2011). Although the objects were visible during the task, the presence of articulatory suppression impaired attentional control and disrupted the potential for visual presentation to serve as an additional modality to support recall. This finding is consistent with prior research (Yang et al., 2014; Allen & Waterman, 2015; Yang et al., 2022), which highlights the advantages of action-based recall in instructional contexts. Taken together, the results suggest that low-WMC individuals may still perform relatively well through action recall, even in the presence of interference. In this context, the tapping task did not appear to overload working memory capacity to the extent that it disrupted performance in following instructions.

This study is not without limitations. First, the baseline (single-task) condition was not included in the same experimental design to directly compare performance with dual-task interference. Nonetheless, significant effects of WMC and instruction type under interference were still found, with large effect sizes. Second, the experimental design specified spoken instructions with articulatory suppression for verbal recall and written instructions with tapping for action recall. As a result, it was not possible to examine performance differences across both types of recall within the same instruction type and interference condition. Despite this, the study findings remain consistent with prior research.

For future research, it is recommended to examine different task conditions across groups. For example, one high-WMC group could complete a single-task condition, while another performs a dual-task condition, with the same arrangement applied to low WMC groups. This design would allow researchers to compare the effects of single and dual-task on both high and low WMC groups in following spoken and written instructions. Additionally, future studies should incorporate both types of recall (verbal and action) for each instruction type under interference conditions. Such a design would provide a clearer understanding of how recall modality interacts with WMC and instructional delivery under cognitive load.

Conclusion

To summarise, this study provides meaningful insights with practical implications for daily life. The findings suggest that interference impairs working memory performance more strongly when tasks require verbal recall compared to action recall. In environments with high levels of verbal noise as interference, shifting towards more action-based activities may serve as a practical solution. Nevertheless, the best practice remains to minimise the influence of distractors to maintain focus, ensure task completion, and improve accuracy.

Acknowledgment
We sincerely thank all participants involved in this study for their valuable contributions.

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